DE GRUYTER OPEN

Environmental & Socio-economic Studies

DOI: 10.1515/environ-2016-0018

Environ. Socio.-econ. Stud., **2016, 4,3: 56-68**

Original article

The volume of wet and dry atmospheric deposition in the area around Goczałkowice Reservoir between 2011-2013

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ABSTRACT

Research on wet and dry pollution deposition was carried out at two measurement points situated on opposite sides of the Goczałkowice Reservoir. On the east side was a station in Goczałkowice and on the west side was a station in Frelichów. Meteorological monitoring was conducted at four points situated in the vicinity of the reservoir. On the basis of the research carried out between 2011-2013 it was concluded that the size of dry and wet deposition in the area of the Goczałkowice Reservoir is diversified in particular years, seasons and months. Due to high precipitation and biological processes (activity of flora and fauna) the pollutant loads in the form of biogenic compounds (nitrogen and phosphorus) are the highest in the summer season. Whereas pollutant inputs in the form of dry deposition are highest in the winter season (heating season), which in the case of a thick ice and snow cover in the spring time causes their accumulation and increased input into the reservoir water (thawing weather, snow-melt season). In relation to the 1970s the size of the deposition became smaller, but in the case of biogenic compounds it was diversified. A decrease was observed in the case of total nitrogen but an increase in the case of phosphorus. On the basis of a comparison of the received results with the data provided by the Provincial Inspector for Environmental Protection and calculated for the annual area deposition of the Pszczyna district in 2011 it appears that deposition of total nitrogen in the reservoir area slightly exceeded the area value. In the case of total phosphorus in relation to the area data the deposition was over twice as high, which indicates that biogenic compounds are still a significant load of atmospheric deposition in the reservoir area.

KEY WORDS: meteorological conditions, biogenic compounds, precipitation, Silesia, Vistula River

ARTICLE HISTORY: received 6 April 2016; received in revised form 17 August 2016; accepted 20 August 2016

1. Introduction

The Goczałkowice Reservoir was formed as a result of the accumulation of waters from the River Vistula caused by the construction of the earth dam, 2980 m in length, between the towns of Goczałkowice-Zdrój and Zabrzeg. A predominant function of the reservoir, which was constructed in 1956, is the retention of potable water for the needs of the inhabitants of the Upper-Silesian Agglomeration. The capacity of the reservoir reaches 165,600,000 m^3, therefore in respect of capacity it is ranked as the fourth potable water reservoir in Poland and as the third in respect of surface area (3,200 ha). Due to the fact that it holds stable flood-control reserves of 45,400,000 m^3 capacity, since it was built, the reservoir has been an essential element in the flood-control system for the area of Upper Silesia. During a drought the reservoir contributes to the maintenance of the minimum flow in the River Vistula below the dam (SIMPSON ET AL., 2011).

Atmospheric pollution carried in a result of dry and wet deposition, along with the pollution carried by the waters of the River Vistula and its tributaries, constitutes the main source of biogenic compounds and other substances which are carried into the reservoir.

The measurements of the size of dry and wet deposition within the dam had already been carried out in previous years, particularly valuable research was done between 1973-75 by the hydrobiological station of the Polish Academy of Sciences (PAN), KASZA (1979), ERISMAN ET AL., (1998, 2001).

2. Methodology and materials

The measurements of the air-pollutant deposition and the chemical composition of the atmospheric precipitation were taken at two measurement points located in the neighbourhood of the Goczałkowice Reservoir. The first point was located by the dam in Goczałkowice (49°56′12″N 18°58′02″E), the second one was in the town of Frelichów (49°55′16″N 18°29′32″E) (Fig. 1).

The measurement period of the wet and dry deposition began on 02.03.2011 and lasted until 01.03.2012. The intention was to collect monthly samples but due to organizational reasons the period of the sample exposition was shortened or prolonged. Nevertheless, the analysis of the concentration was always related to the size of the deposition in a monthly cycle. Time intervals between the measurements are presented in Fig. 2.

The results were compared with the archived data from 1973-1975 (KASZA, 1979) and the area data for the Province of Silesia (REPORT ON THE CONDITION OF THE ENVIRONMENT IN THE SILESIA REGION, 2000, 2001, 2011, 2012).

The measurements were taken by a deposition sampler produced by Loda Electronics Co. model 2005, Chemical analysis of samples were undertaken by the laboratory of the Institute of environmental engineering Polish Academy of Sciences in Zabrze according to the guidelines of EMEP.

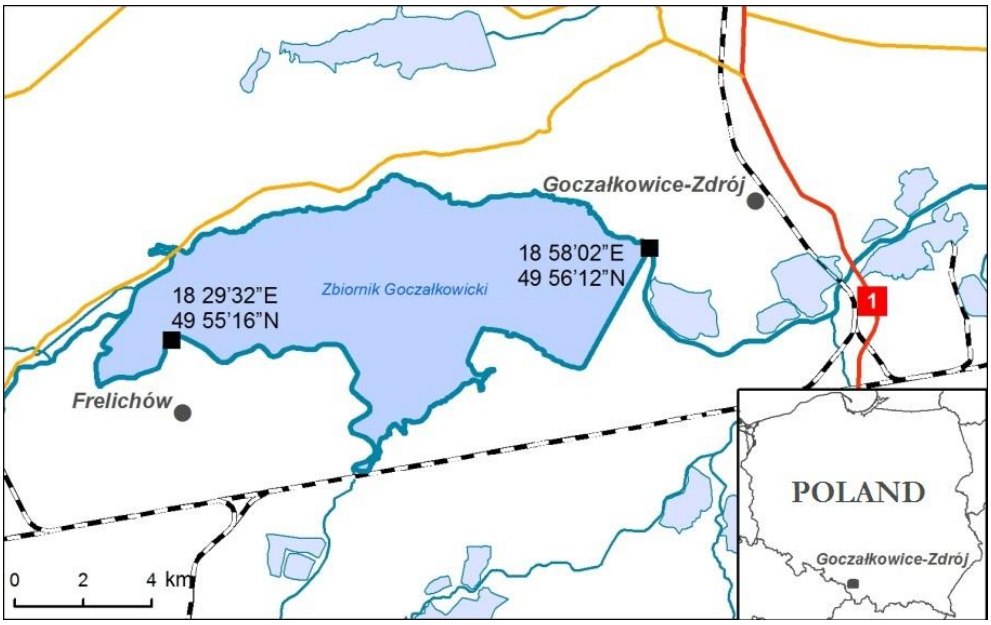

Fig. 1. Location of the measurement points in Goczałkowice and Frelichów

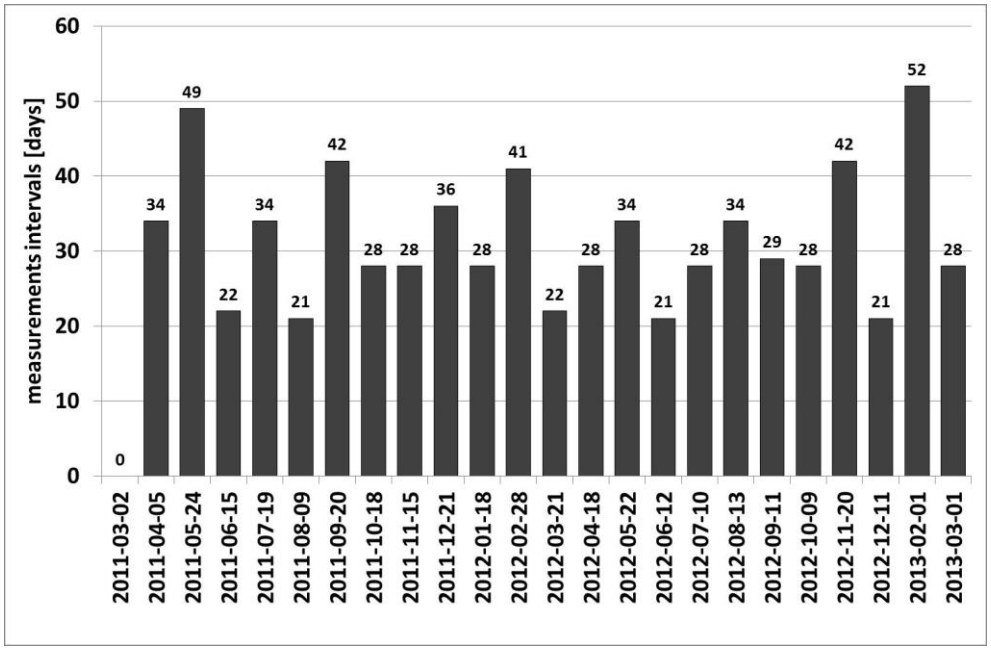

Fig. 2. Time intervals between the measurements

3. Meteorological conditions

A significant diversification of the meteorological conditions at the particular research points was observed on the basis of the results from the measurements taken between 2010 and 2012. At the base point of the Goczałkowice-Dam mean annual air temperature fluctuated from 10.6°C (2010), 10.4°C (2012) to 9.2°C (2011) which was calculated according to the monthly average temperatures of years: 2010, 2011, 2012 (Fig. 3).

Precipitation distribution in Goczałkowice in 2010-2012 especially in spring and summer, was highly diversified. The highest annual total fell in 2010 and amounted to 863 mm. At the nearest IMGW (the Institute of Meteorology and Water Management) station in Racibórz, which was within the region, represents similar meteorological conditions, it was 834 mm. While mean annual precipitation total for Goczałkowice in the period 1968-2000 was 802 mm. Also in 2010 the highest monthly maximum was observed, this total fell in May and amounted to 281 mm. July 2011 was a month abundant in rainfall (171 mm in total) as well as August 2010 (138.6 mm in total). The highest daily total fell in May 2010 and was 60.6 mm with a momentary intensity of 8 mm/h. 2011 was a year moderate in rainfall and its annual total for Goczałkowice was 536 mm (506 mm in Racibórz) (Fig. 4).

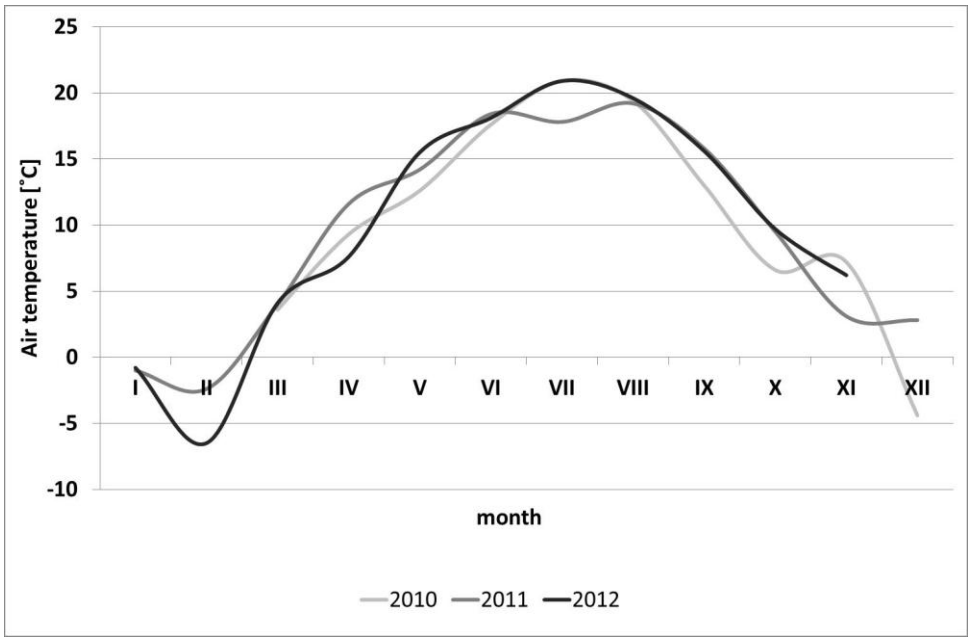

Fig. 3. Monthly average temperature distribution in Goczałkowice in 2010-2012

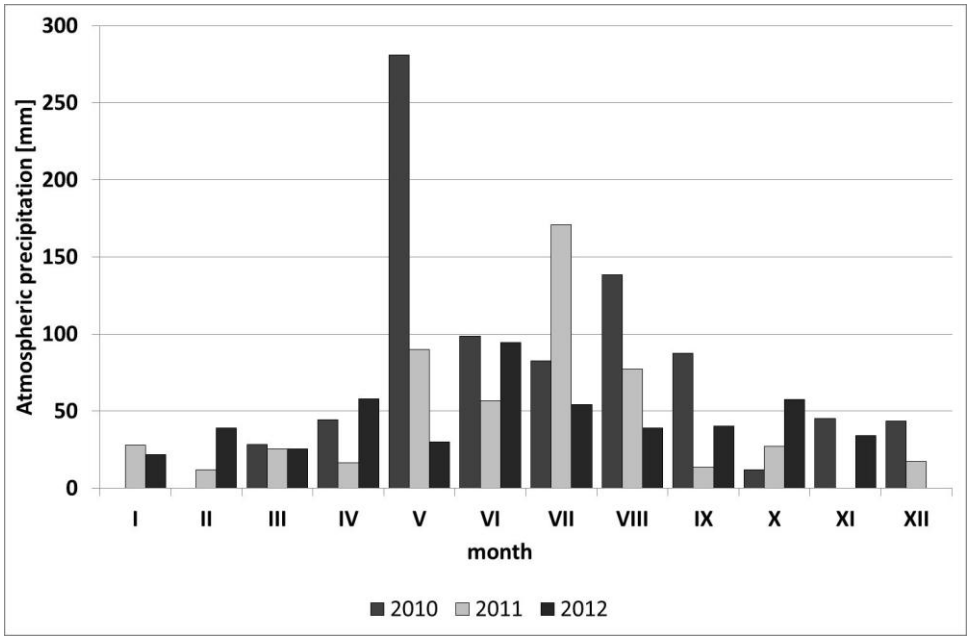

Fig. 4. Distribution of monthly precipitation totals in Goczałkowice between 2010-2012

Variation in the wind direction clearly indicates this connection with the main directions of the atmospheric circulation and topographical conditions. A clear 22.7% domination of south-westerly winds (SW) was observed during the period between 1971-90 in the area of the Pszczyna Plain, almost the same frequency was obtained for western winds (W) 11.5% and easterly winds (E) 10.9%. The least frequent were northerly winds (N) 3.2% (KOZŁOWSKA-SZCZĘSNA, 2002). There was a similar predominance of wind directions coming from the south-west (W-SW) and north-east (NE) observed between 2010 and 2012. The orientation of the reservoir confirms the dominant inflow of air from these directions, which are additionally reinforced by the orientation of the reservoir channel. Due to this fact it should be emphasised that during the years of this research the mean wind direction did not differ much from the direction in the particular years for the period of 2010-2012 or previous years. The maintenance, over the past decades, of the constant inflow of air along the axis of W-WS and NE sectors leads to the conclusion that pollution carried in the form of horizontal movements of air masses flows over the area of Goczałkowice mainly from the area of the Ostrawsko-Karwinski Coal Basin and eastern parts of the Upper Silesian Industrial Region along with the Oświęcim Basin (Fig. 5).

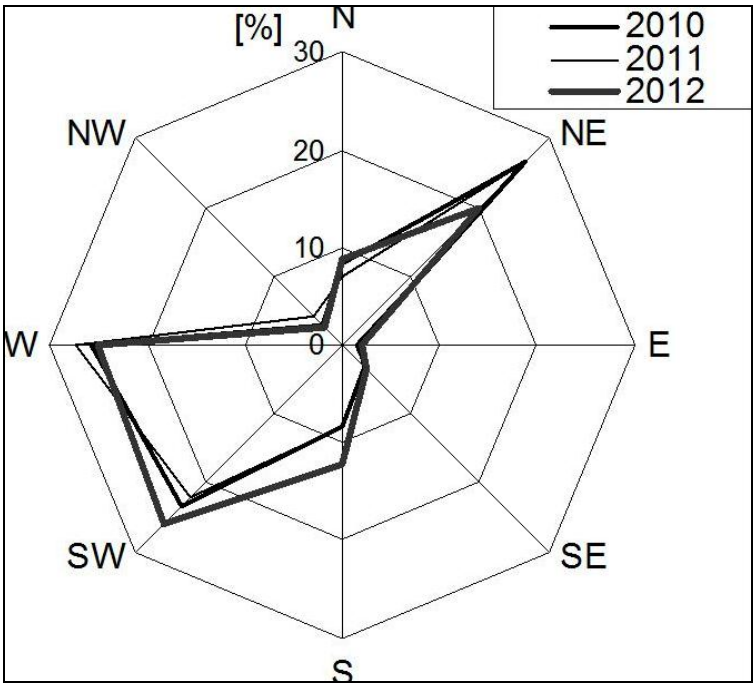

Fig. 5. Wind rose for the Goczałkowice station in 2010-2012

4. Atmospheric deposition

The methodology applied to the measurement of wet and dry deposition allowed us to estimate the quantity in which the selected groups of chemical elements and their compounds were carried into the Goczałkowice Reservoir (LEŚNIOK, 1996).

4.1. Wet deposition

Table 1 and Figure 6 present mean values for calcium, magnesium, iron, chlorine, nitrogen, phosphorus, potassium and sodium, the elements which were carried with the atmospheric precipitation during the period between 02.03.2011 to 01.03.2013 at the measurement points localized within the area of Goczałkowice, Frelichów, (measuring intervals are shown in Fig. 2) Katowice and Racibórz (monthly values) from REPORT ON THE CONDITION OF THE ENVIRONMENT IN THE SILESIA REGION for 2000, 2001, 2011 and 2012.

During the period analysed the highest mean contents of such elements as calcium, magnesium, iron, chlorine and potassium in the precipitation water were found in Katowice (Ca 9.32 kg·ha^{-1}; Mg 5.33 kg·ha^{-1}; Fe 2.26 k kg·ha^{-1}; Cl 8.0 kg·ha^{-1}; K 8.94 kg·ha^{-1}). The lowest mean values among the elements, except for iron, were found in Frelichów (Ca 2.49 kg·ha^{-1}; Mg 0.17 kg·ha^{-1}; Cl 4.89 kg·ha^{-1}; K 2.77 kg·ha^{-1}). Analysing the mean contents of total nitrogen and total phosphorus it may be concluded that the highest concentrations in precipitation water were taken in Frelichów (N_{total} 8.97 kg·ha^{-1}, P_{total} 1.04 kg·ha^{-1}) whereas the lowest mean values of these elements were found in Racibórz (N_{total} 0.56 kg·ha^{-1}, P_{total} 0.23 kg·ha^{-1}). The highest mean

content of sodium was found in Frelichów 2.38 kg·ha^{-1}, while the lowest was in Racibórz 0.16 kg·ha^{-1} (Tab. 1, Fig. 6).

A graph was created in order to analyse the way in which mean values of the aforementioned elements in the wet deposition water change according to the season and shows a division into the summer season including the months from April to September and the winter season including the months from October to March (Tab. 2).

Table 1. Total values of pollutant load in 2011 and 2012 for Goczałkowice, Frelichów, Katowice and Racibórz [kg·ha^{-1}]

	Goczałkowice	Frelichów	Katowice	Racibórz
	2011-12	2011-12	2011-12	2011-12
Ca	6.21	2.49	9.32	4.49
Mg	0.50	0.17	5.33	2.61
Fe	0.23	0.47	2.26	1.91
Cl	5.28	4.89	8.00	4.95
N-total	7.06	8.97	0.95	0.56
P- total	0.81	1.04	0.45	0.23
K	3.24	2.77	8.94	8.87
Na	2.33	2.38	0.33	0.16

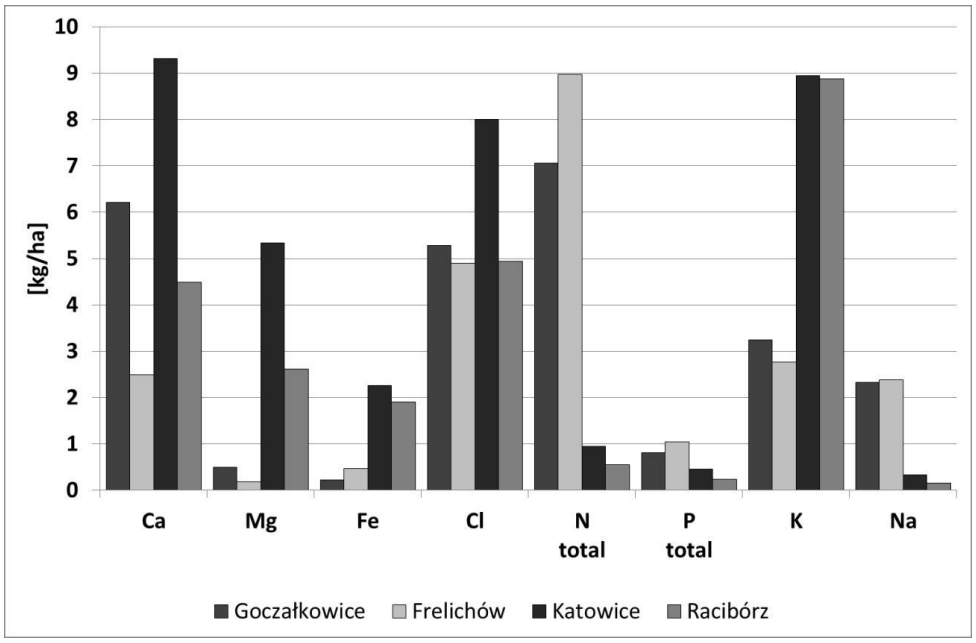

Fig. 6. Total values of wet deposition for Goczałkowice, Frelichów, Katowice and Racibórz between 2011-2012 [kg·ha^{-1}]

Table 2. Mean pollutant load values for seasons in 2011 and 2012 for Goczałkowice, Frelichów, Katowice and Racibórz [kg·ha^{-1}]

	Summer season during the months IV-IX				Winter season during the months X-III			
	Goczałkowice	Frelichów	Katowice	Racibórz	Goczałkowice	Frelichów	Katowice	Racibórz
Ca	4.84	1.95	4.97	3.37	1.37	0.54	3.17	0.98
Mg	0.17	0.07	0.57	0.37	0.32	0.11	0.4	0.12
Fe	0.19	0.41	0.27	0.15	0.04	0.06	0.12	0.05
Cl	3.20	3.22	3.50	2.21	2.08	1.67	5.04	1.74
N-total	5.61	7.53	5.49	6.18	1.45	1.44	2.27	1.90
P-total	0.63	0.88	0.18	0.10	0.18	0.16	0.14	0.04
K	1.79	1.65	1.13	1.06	1.44	1.12	0.67	0.74
Na	1.64	1.57	3.41	1.51	0.69	0.81	1.83	0.71

In summer season mean values of almost all of the analysed elements, found in the precipitation water in the area of Goczałkowice, Frelichów, Katowice and Racibórz, were clearly higher than the mean values of these elements in the winter season. An exception to this was for the mean value of chlorine taken in Katowice, which was higher in the winter season than in the summer season. The biggest difference between the seasons can be observed in the cases of Ca, Cl and total N. During the analysed period the mean values of Mg and Fe were the same and independent of the season (Tab. 2, Fig. 7, Fig. 8).

Analysis of the data collected allowed us to find the answer to the question concerning the way mean values of such elements as: Ca, Mg, Fe, Cl, total N, total P, K and Na, change and how they were carried into the atmospheric precipitation water over the area of Goczałkowice during the last thirty year period of. In order to achieve an answer a comparison was drawn between the mean concentration values of the selected elements in 2011-2012 with the mean values of these elements in the period 1973-1975 (KASZA, 1979).

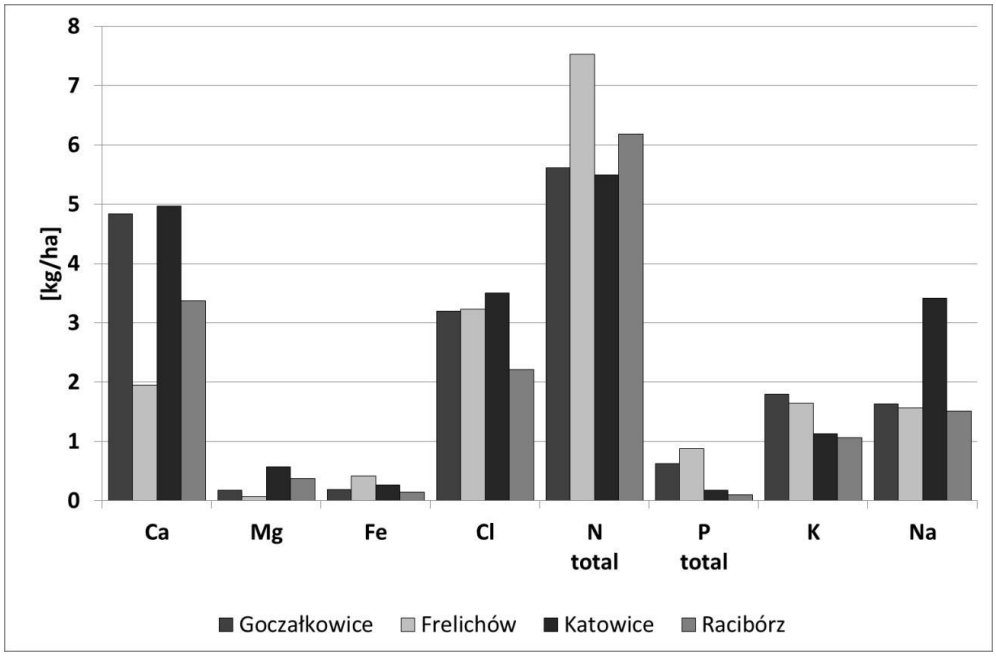

Fig. 7. Mean values of wet deposition in the summer season for Goczałkowice, Frelichów, Katowice and Racibórz between 2011-2012 [kg·ha^{-1}]

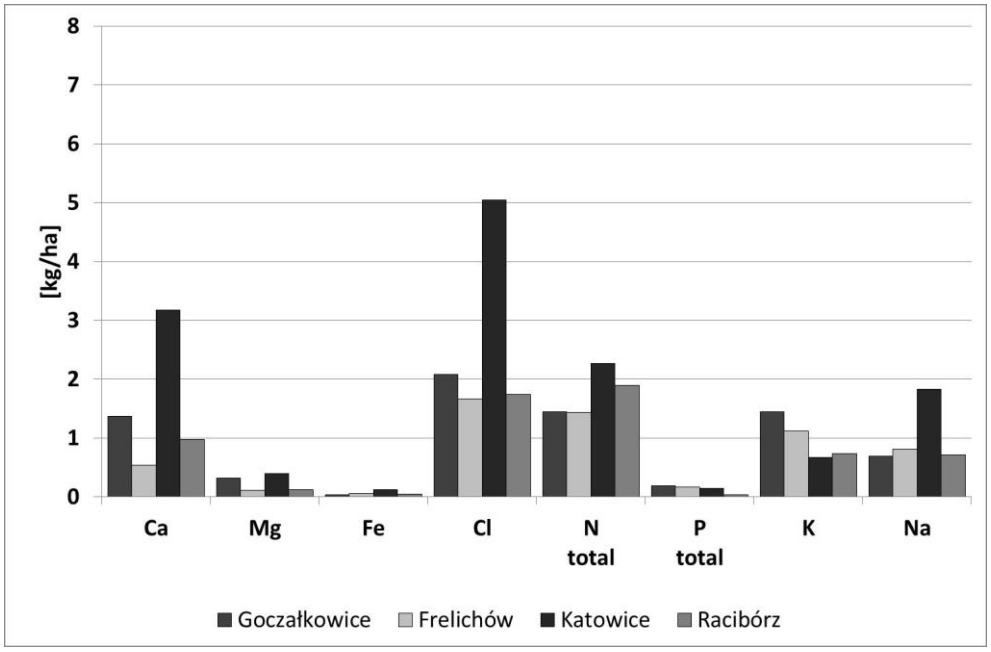

Fig. 8. Mean values of wet deposition in the winter season for: Goczałkowice, Frelichów, Katowice and Racibórz between 2011-2012 [kg·ha^{-1}]

Table 3 presents the change which occurred in mean concentrations of the selected elements found in precipitation water in the neighbourhood of the Goczałkowice Reservoir within the last 37 years.

There was a decrease in the concentrations in precipitation water for all of the analysed elements except for total phosphorus in the period 2011-2012, compared with the mean values taken between 1973-1975.

Taking into consideration the compared periods and the aspect of time, magnesium was characterized by the biggest change, just under forty fold (a decrease of 95.7% in relation to the previous period). Potassium showed the smallest change in its concentration (a decrease of 5.88% in relation to the previous period).

Mean content of calcium decreased by almost four fold (a decrease of 74%), content of iron and chlorine decreased by over four fold (decreases of 60.68% and 63.06%). Mean content of total nitrogen decreased almost two fold which was a decrease of 46.47% in relation to the mean value between 1973-1975. Sodium decreased by 31.34% compared with the previous period. The mean content of total phosphorus increased by 352.18% during the analysed period between 2011-2012 in relation to the mean value between 1973-1975 (Tab. 3, Fig. 9).

Table 4, presents a time change in mean values of the selected elements in precipitation water in the neighbourhood of the Goczałkowice Reservoir from a seasonal perspective for the periods 1973-1975 and 2011-2012 (summer season includes the months from April to September and winter season from October to March).

Table 3. Total values for pollutant load in 1973-1975 and 2011-2012 for Goczałkowice [kg·ha^{-1}]

	Goczałkowice			
	1973-1975	2011-2012	Difference	% decrease/ increase
Ca	24.06	6.21	17.85	-74.20
Mg	11.54	0.50	11.04	-95.70
Fe	0.58	0.23	0.35	-60.68
Cl	14.3	5.28	9.02	-63.06
N-total	13.19	7.06	6.13	-46.47
P- total	0.23	0.81	0.58	+352.18
K	3.44	3.24	0.20	-5.88
Na	3.39	2.33	1.06	-31.35

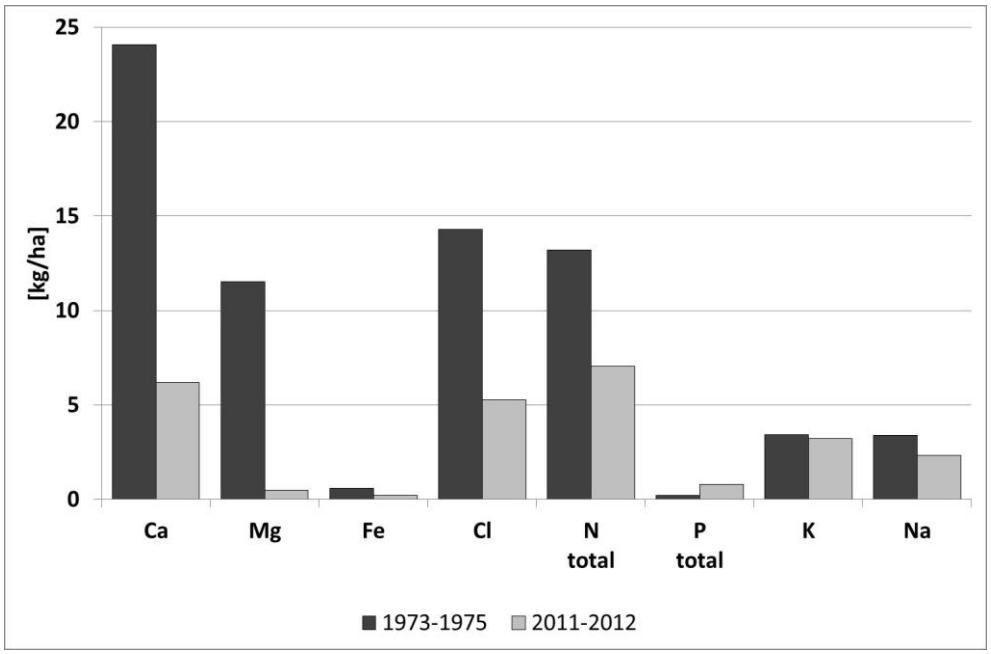

Fig. 9. Mean wet deposition values for Goczałkowice for the periods 1973-1975 and 2011-2012 [kg·ha^{-1}]

Comparing mean values for the seasons within the 37 year period it can be concluded that, similar to the case discussed above, in relation to the previous period, there are visible decreases in the concentrations of the analysed elements in the precipitation water. In seasonal comparison as time goes by the decreasing tendencies are visible for all of the analysed elements, except of total phosphorus which stays in the opposite relation during both seasons (Tab. 4, Fig. 10).

On the basis of the above values it was possible to estimate a mean amount for the pollutant load for the selected elements and chemical compounds, which in 2011-2012 were directly carried onto the surface of the Goczałkowice Reservoir from the atmospheric precipitation (Tab. 4). Taking into account the surface area of the Goczałkowice Reservoir (3,200 ha) the following mean pollutant load values were obtained in tonnes for the summer season: Ca 15.49; Mg 0.54; Fe 0.61; Cl 10.24, $_{total}$N 17.95; $_{total}$ P 2.02. K 5.73, Na 5.25. While for the winter season the following values were obtained: Ca 4.38; Mg 1.02; Fe 0.13; Cl 6.66; $_{total.}$N 4.64; $_{total}$P 0.58; K 4.61; Na 2.21. After the seasonal totalling for the whole year the following mean values were obtained in tonnes: Ca19.87; Mg 1.57; Fe 0.74; Cl 16.90; $_{total.}$N 22.59; $_{total}$ P 2.59; K 10.34; Na 7.46 (Tab. 4, Fig. 11).

Table 4. Mean seasonal pollutant load values for the periods 1973-1975 and 2011-2012 for Goczałkowice [kg·ha^{-1}]

Goczałkowice				
	Summer season IV-IX 1973-1975	Summer season IV-IX 2011-2012	Winter season X-III 1973-1975	Winter season X-III 2011-2012
Ca	12.76	4.84	11.30	1.37
Mg	7.14	0.17	4.40	0.32
Fe	0.33	0.19	0.24	0.04
Cl	7.58	3.20	6.71	2.08
N-total	8.00	5.61	4.51	1.45
P- total	0.15	0.63	0.08	0.18

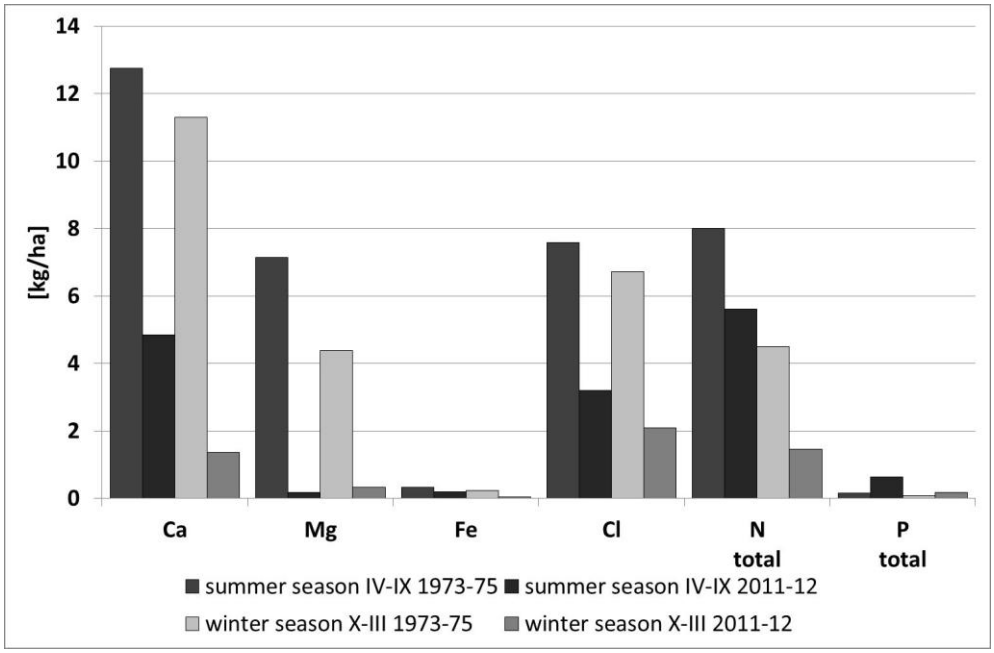

Fig. 10. Mean wet deposition values for seasons in the periods 1973-75 and 2011-12 Goczałkowice [kg·ha^{-1}]

The size of the chemical substance load carried in the form of direct atmospheric precipitation is dependent on both the concentration of a given component in the precipitation as well as on the amount of precipitation. It can be observed that on average in the summer season a significantly higher amount of chemical compounds is carried onto the surface of the reservoir. This situation takes place as a result of the direct correlation that occurs between the amount of precipitation and the chemical compounds existing in the atmospheric air. Special attention should be given to the annual load value of phosphorus and total nitrogen because they contribute to the eutrophication of the reservoir

($_{total.}$N) 22.59 [t], $_{total}$ P 2.59 [t]). Expressed in hectares it accounts for 7.06 kg $_{total}$N and 0.81 kg $_{total}$P. Comparing the obtained values with the results of the analysis carried out in 2008 for Lake Dobre, situated in Northern Poland where the mean annual content of nitrogen carried along with the precipitation was estimated at 74.3 kg·ha^{-1} and for phosphorus at the level of 9.8 kg·ha^{-1}, it can be concluded that regarding the carried load of nitrogen and phosphorus in the atmospheric form no significant differences occur between these two reservoirs (Fig. 11).

For comparison, the atmospheric deposition of mineral nitrogen in the vicinity of Łeba was slightly over 6kg N/ha (mean value for the period of 1995-2004). Whereas SAPEK AND ET AL. (2003) stated that on agricultural areas as a result of the vertical input the carried load is 18kgN/ha and 0,4kg P/ha within a year. BAJKIEWICZ-GRABOWSKA (2002) claimed that in the case of a highly urbanized catchment, the annual input of mineral nitrogen with atmospheric precipitation can increase from 2 to 27.5 kg N/ha, while the input of phosphorus can vary between 0.2 to 1.63 kgP/ha (JAROSIEWICZ, 2012).

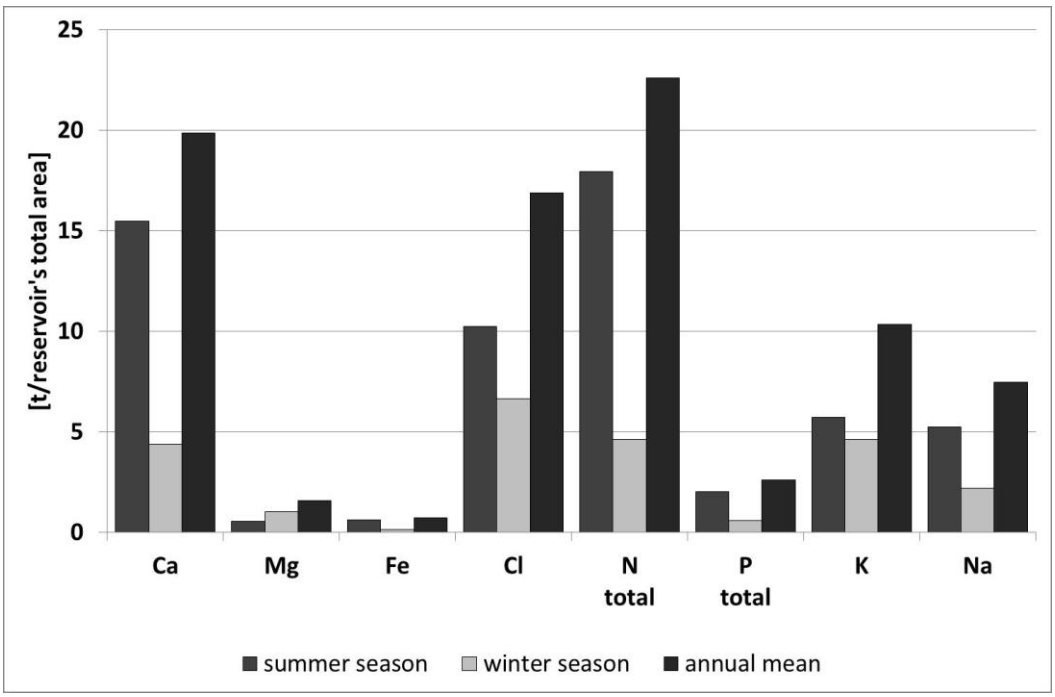

Fig. 11. Mean annual, and mean seasonal, pollutant load carried with precipitation onto the surface of Goczałkowice Reservoir in 2011-2012 in [t]

4.2. Dry deposition

Table 5 presents monthly mean annual values of dry precipitation for the selected metals (iron, chrome, cobalt, nickel, copper, cadmium, zinc, manganese and lead), which were recorded in Goczałkowice and Frelichów during the period 2011-2012. Comparing the recorded values with the data for the period of 2000-2001 it can be stated that there was a significant decrease in the deposition of all of the analysed metals.. In the case of all of the analysed metals the comparison of monthly mean values of dry deposition in 2011-2012 with the earlier period of 2000-2001 revealed at least a 50% reduction in the amount of the recorded metals carried via the atmosphere onto the surface of the area in the vicinity of the Goczałkowice Reservoir Dam (Tab. 6).

Comparing the values of dry deposition for the area of Goczałkowice within less then a decade it can be stated that among the analysed metals the biggest decreases were observed in the cases of zinc and cadmium (92.73% and 91.22%). Decrease of over seventy percent was observed for cobalt and lead (78.72%, 77.89%). Within the space of a decade a decrease of over 60% (61,48%, 60,18%) was recorded for manganese and nickel, for the other elements (copper, chrome and iron) it fluctuated in the region of fifty percent (Tab. 6, Fig. 12, 13 and 14).

Table 5. Total annual dry deposition values in Goczałkowice in 2000, 2001, 2011, 2012. [mg/m^2], Fe* – [g/m^2]

Goczałkowice				
	2000	2001	2011	2012
Fe*	0.30	0.80	0.32	0.22
Cr	1.20	0.60	0.32	0.56
Cd	0.28	0.86	0.06	0.04
Co	0.42	0.45	0.12	0.06
Ni	1.70	1.30	0.78	0.41
Cu	4.00	4.00	3.10	0.87
Zn	47.00	135.00	8.26	4.97
Mn	13.00	15.00	7.34	3.45
Pb	10.00	9.00	2.52	1.69

Table 6. Mean values of dry deposition in Goczałkowice in 2000- 2001, 2001-2012. [mg/m^2], Fe* – [g/m^2]

Goczałkowice				
	Mean for 2000-2001	Mean for 2011-2012	Difference	% decrease
Fe*	0.55	0.27	-0.28	50.98
Cr	0.90	0.44	-0.46	51.35
Cd	0.57	0.05	-0.52	91.22
Co	0.44	0.09	-0.34	78.72
Ni	1.50	0.60	-0.90	60.18
Cu	4.00	1.99	-2.01	50.35
Zn	91.00	6.61	-84.39	92.73
Mn	14.00	5.39	-8.61	61.48
Pb	9.50	2.10	-7.40	77.89

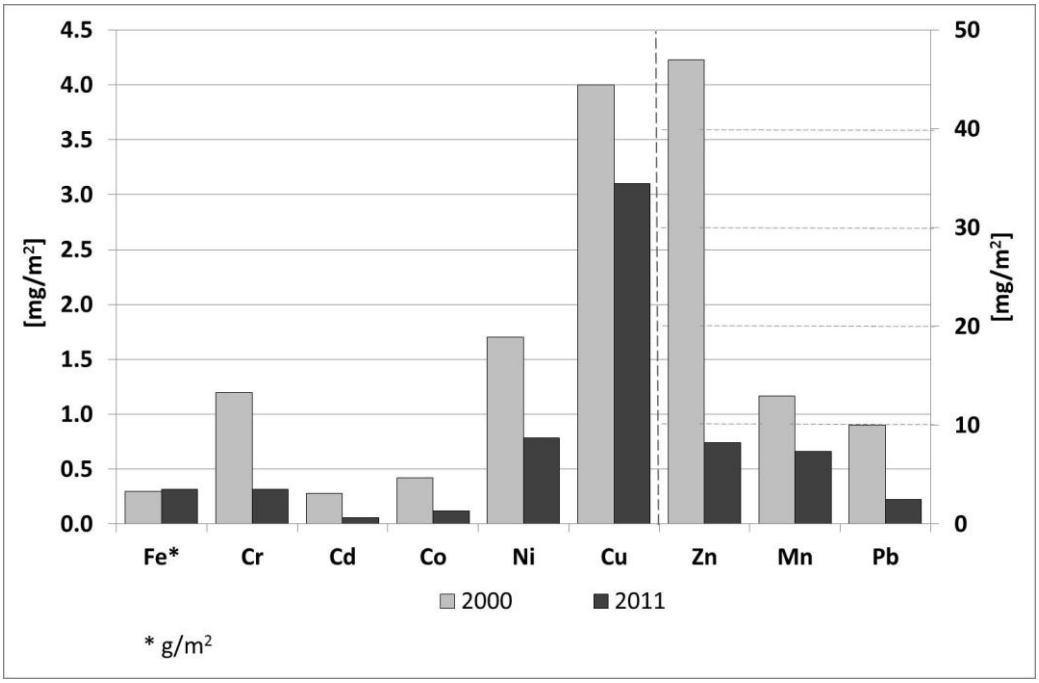

Fig. 12. Mean annual dry deposition values for the selected metals in Goczałkowice in 2000 and 2011 in [mg/m^2], Fe* – [g/m^2]

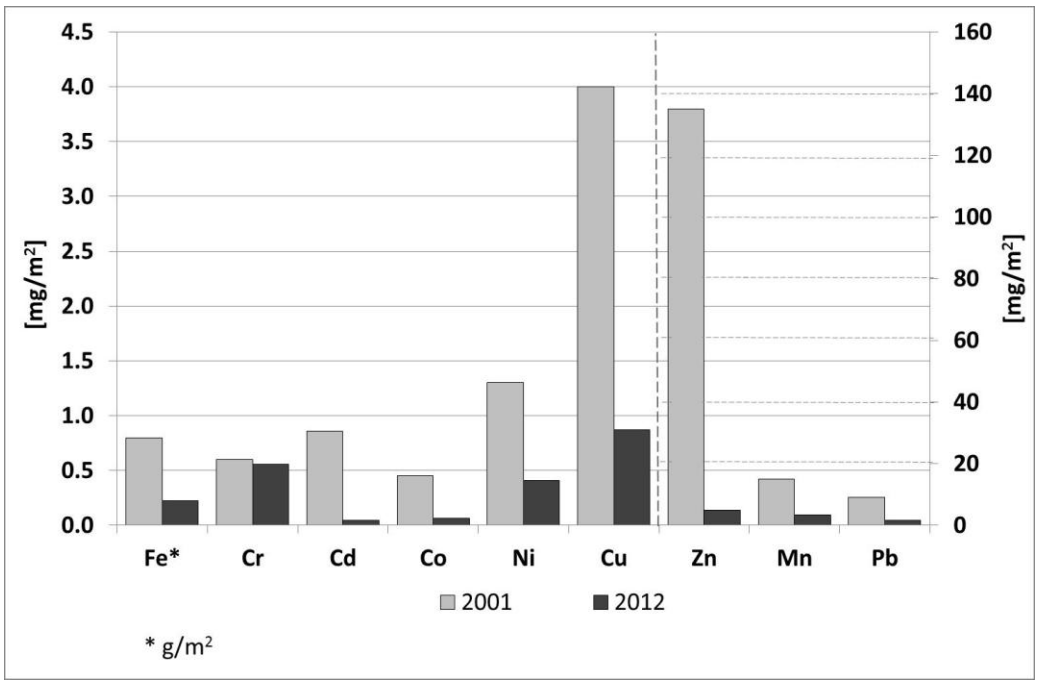

Fig. 13. Mean annual dry deposition values for the selected metals in Goczałkowice in 2001 and 2012 in [mg/m²], Fe* – [g/m²]

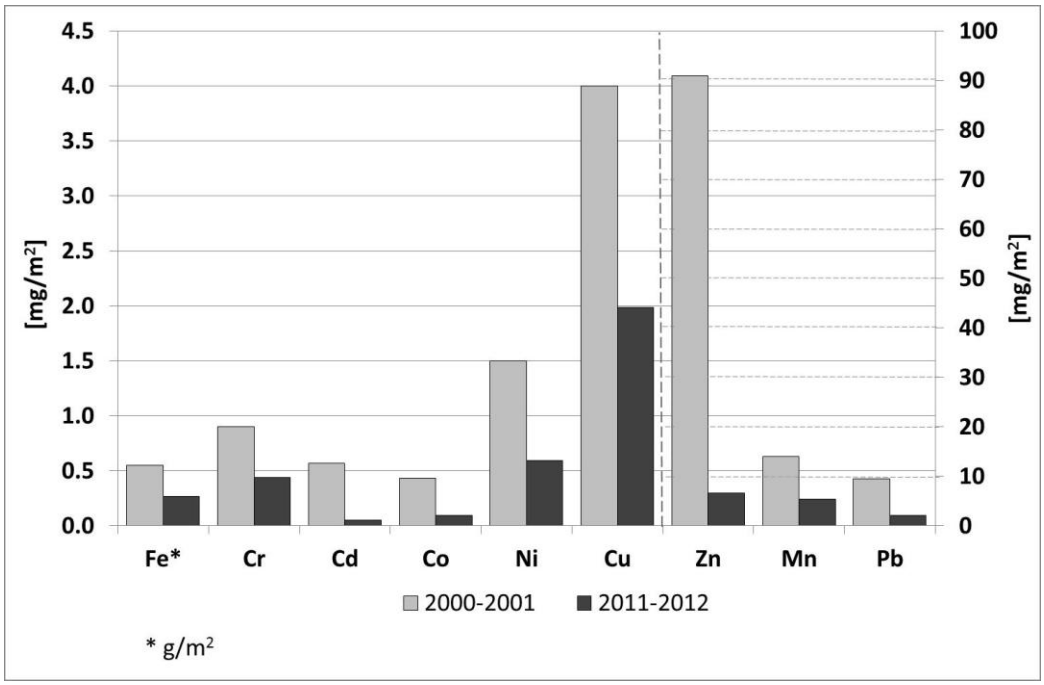

Fig. 14. Mean dry deposition values for the selected metals in Goczałkowice in 2000-2001 and 2011-2012 in [mg/m²], Fe* – [g/m²]

Table 7 presents mean deposition values of the selected metals in the dry form in Goczałkowice and Frelichów which were carried into the environment during the period between 2011 and 2012. Comparing both stations it can be observed that mean values of the analysed metals at both measurement points reached a similar level. In comparison with Frelichów in Goczałkowice elements such as iron, chrome, cobalt and lead reached lower values, whereas mean values of cadmium, nickel, zinc and manganese were higher in Frelichów. The mean value of copper in both cases was the same (1.99 mg/m²). The highest difference in the mean value between the stations was observed for chrome (0.66 mg/m²) (Tab. 7, Fig. 15).

Table 7. Mean dry deposition values for Goczałkowice and Frelichów in 2011-2012 [mg/m^2], Fe* – [g/m^2]

	Frelichów	Goczałkowice
	2011-2012 mean	
Fe*	0.32	0.27
Cr	1.11	0.44
Cd	0.04	0.05
Co	0.13	0.09
Ni	0.52	0.60
Cu	1.99	1.99
Zn	6.12	6.61
Mn	4.91	5.39
Pb	2.20	2.10

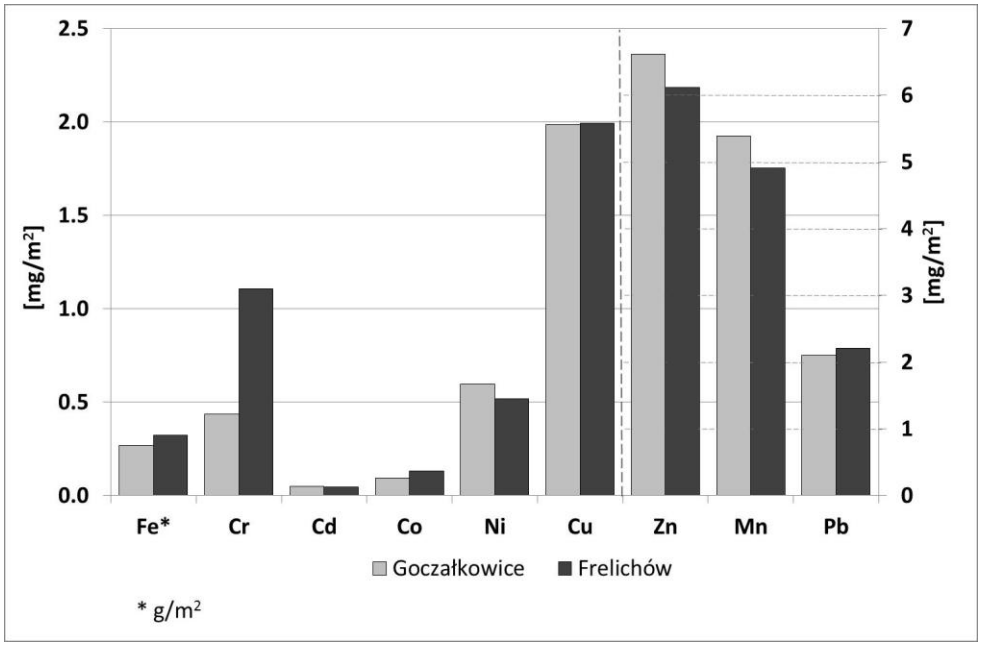

Fig. 15. Mean dry deposition values of the selected metals in Goczałkowice and Frelichów in 2011-2012 in [mg/m^2], Fe* – [g/m^2]

5. Summary and conclusions

The size of dry and wet deposition in the area of the Goczałkowice Reservoir is different both within particular years and months. The research was carried out in two places: Goczałkowice Reservoir and Frelichów. Due to high precipitation and biological processes (activity of flora and fauna) the pollutant loads in the form of biogenic compounds (nitrogen and phosphorus) are highest in the summer season. Whereas pollutant inputs in the form of dry deposition are highest in the winter season (heating season), which in the case of thick ice and snow cover in the spring time causes an accumulation and increased input into the reservoir water (thawing weather, snow-melt season). In relation to the 1970s the size of the deposition became smaller, but in the case of biogenic compounds it was divers (RUSSELL ET AL., 1998). A decrease was observed in the case of total nitrogen but there was an increase in the case of phosphorus. On the basis of comparison of the received results with the data provided by the Provincial Inspector for Environmental Protection and calculated for the annual area deposition of the Pszczyna district in 2011 it appears that deposition of total nitrogen in the reservoir area slightly exceeds the area value. In the case of total phosphorus in relation to the area data the deposition was over twice as high, which indicates that biogenic compounds are still a significant load of atmospheric deposition in the reservoir area. Therefore, the atmospheric deposition requires further monitoring, and a search is necessary for methods of reducing the input of nitrogen and phosphorus compounds in the area of the reservoir (e.g. a reduction of low pollutant emission – especially from settlements). Comparison of mean

values of the selected metals in the form of dry deposition which are currently taken in the region of the Goczałkowice Reservoir with their mean values from the beginning of the 21st century indicate a decreasing tendency. The observed decrease in the quantity of metals in the atmosphere is a reflection of the changes taking place in the industrial structure of the area of Silesia and Podbeskidzie.

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